Numerical investigation of nonlinear wave interaction with a submerged object

THE UNIVERSITY OF EDINBURGH
SCHOOL OF ENGINEERING
INSTITUTE FOR ENERGY SYSTEMS

&

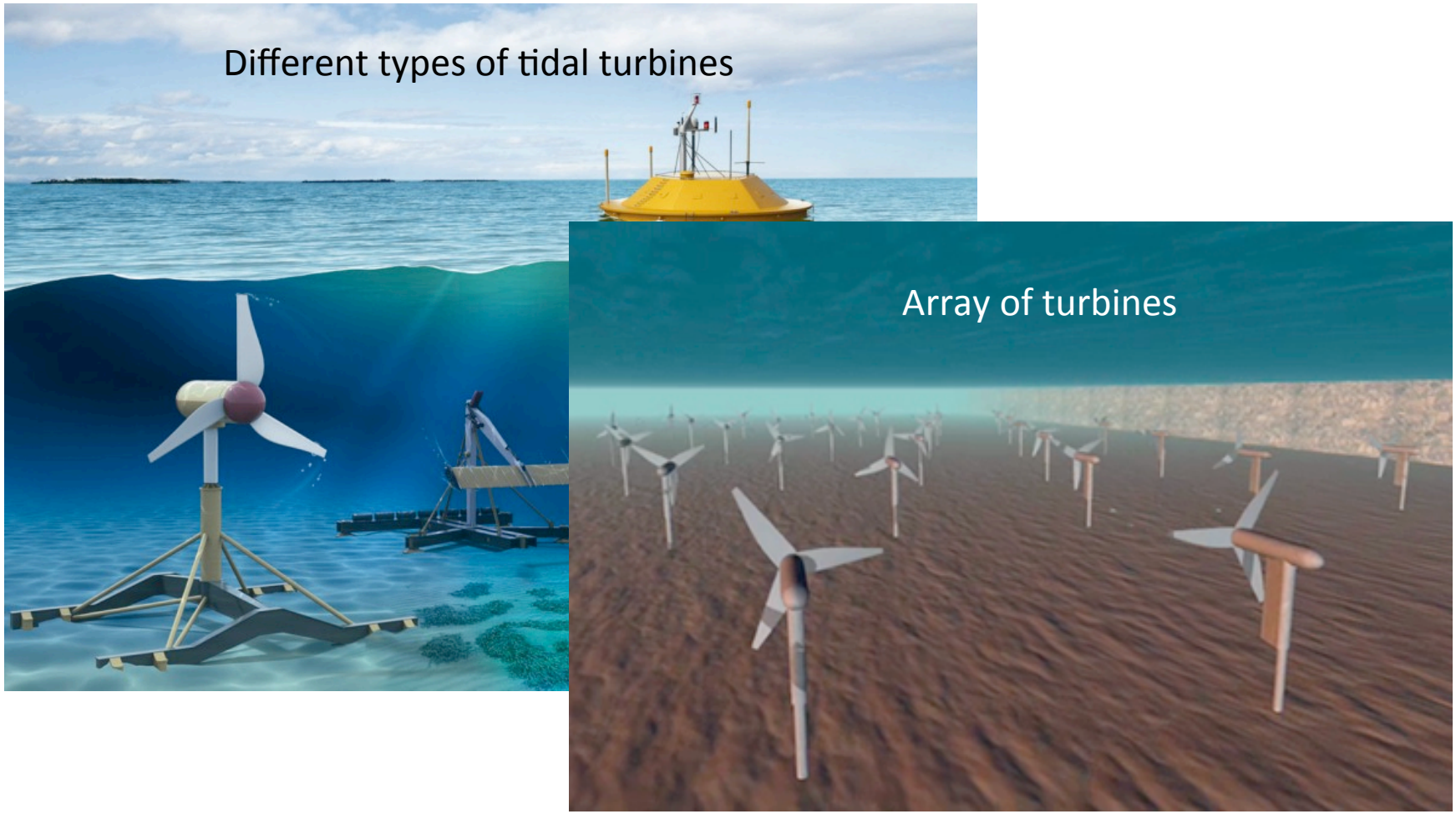
DALIAN UNIVERSITY OF TECHNOLOGY
STATE KEY LABORATORY OF COSTAL AND OFFSHORE ENGINEERING

Numerical investigation of nonlinear wave interaction with a submerged object

Prof Dezhi Ning, Dr Qingxin Li
Dr Ignazio Maria Viola*

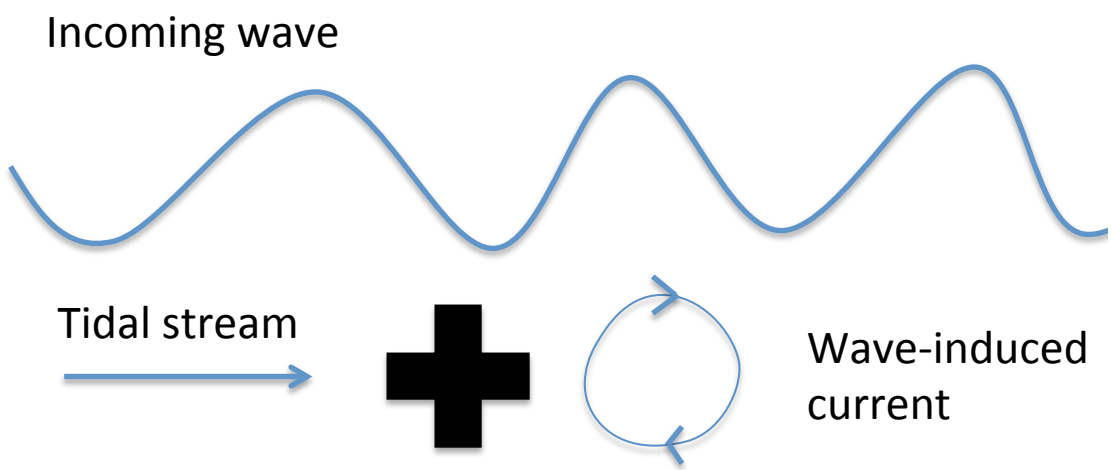
Motivation

Tidal energy could be the next generation of renewable energy technology



Motivation

The wave-induced current is added to the tidal stream velocity leading to flow and pressure fluctuations that compromise reliability

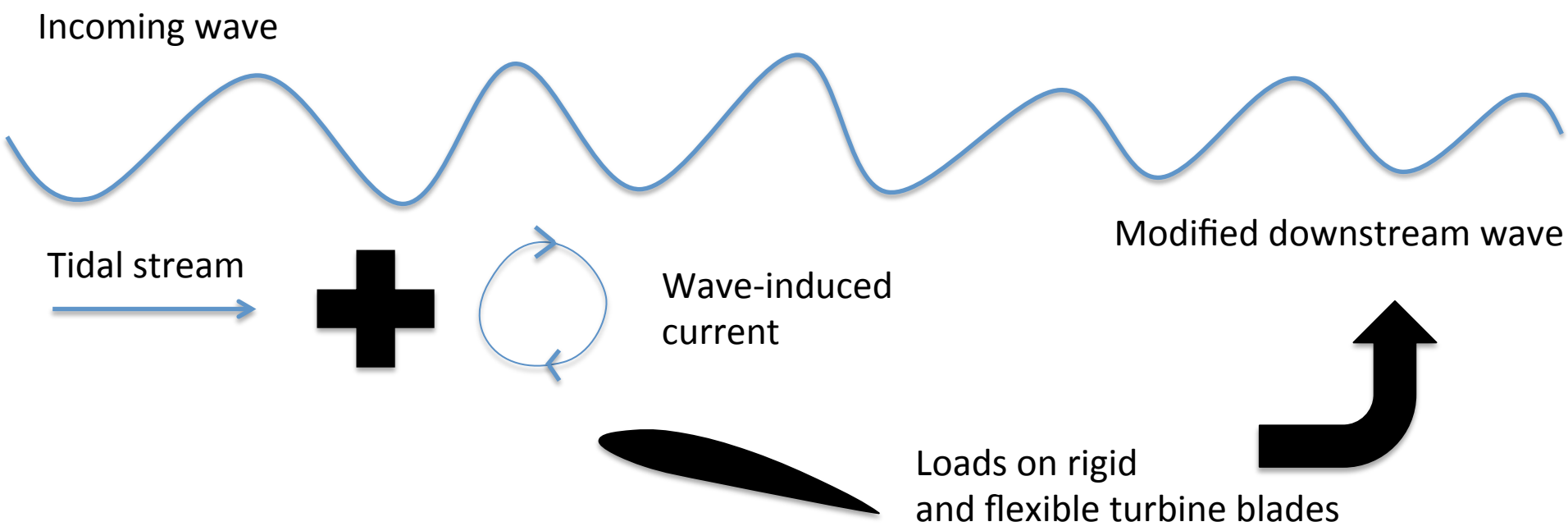


1. Large peak loads in extreme wave conditions can compromise survivability
2. Periodic wave-induced current limit the fatigue life

Loads on rigid and flexible turbine blades

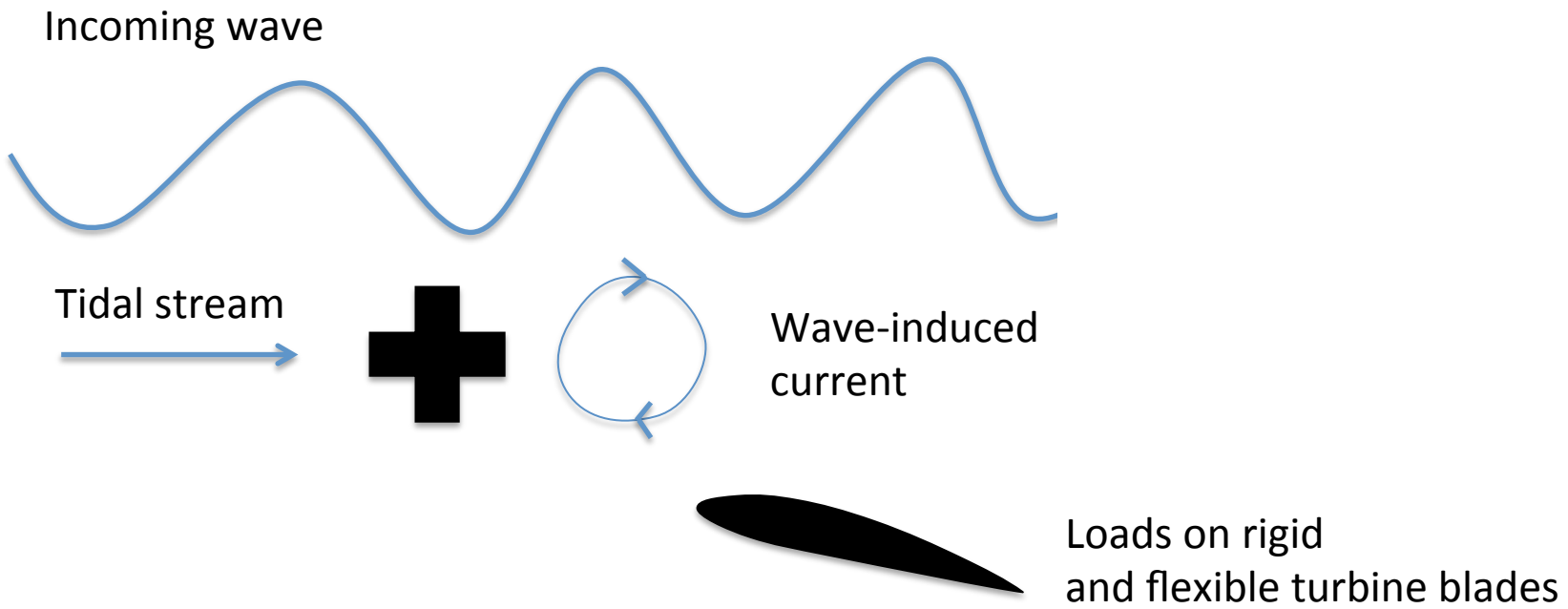
Motivation

Understand the interaction between the tidal turbine, current and wave, both upstream and downstream of the turbine



1. Effect of wave on turbine

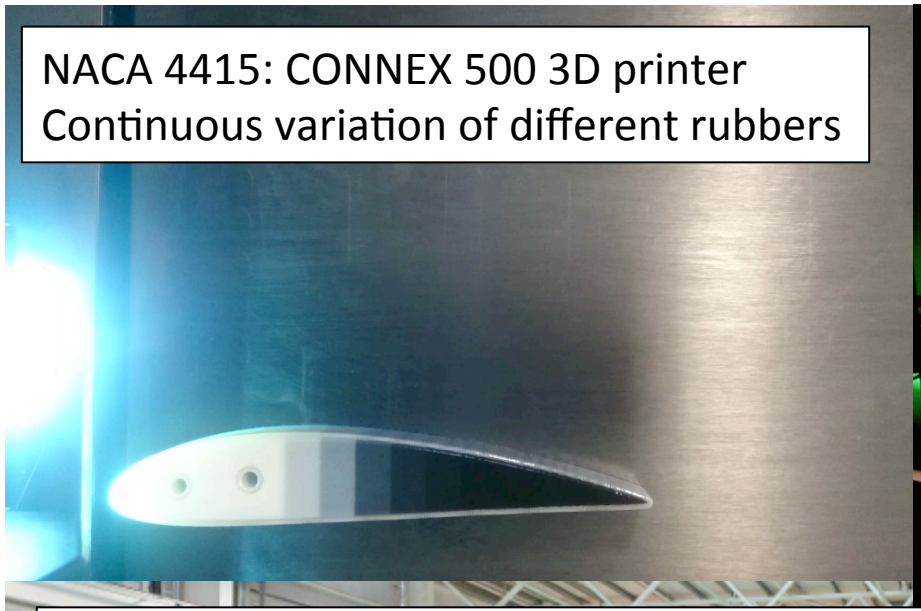
- Investigate dynamic loads on the blade
- Develop technologies to minimise load fluctuations

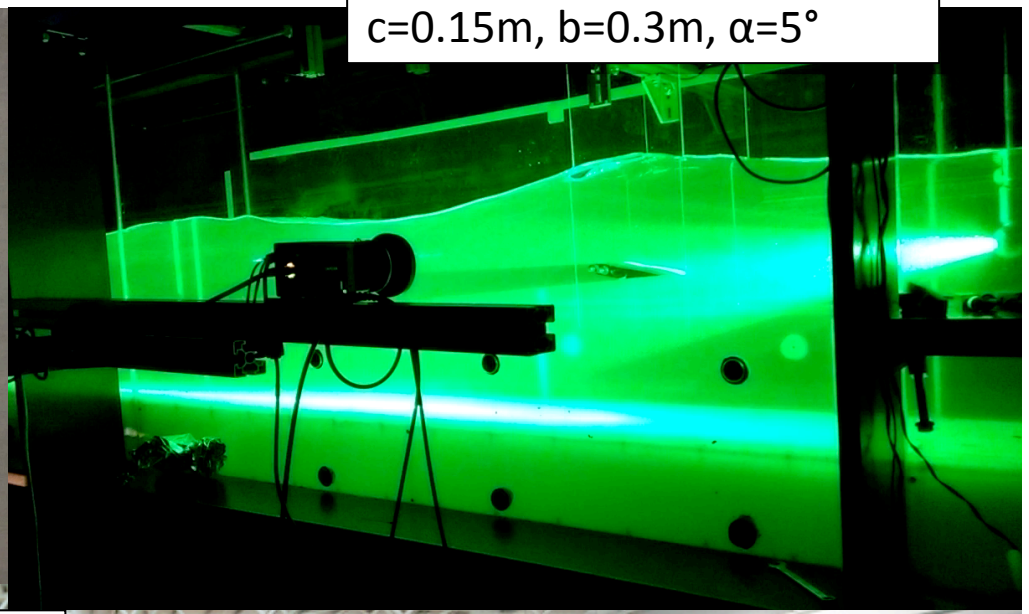


UoE hydrodynamic laboratory

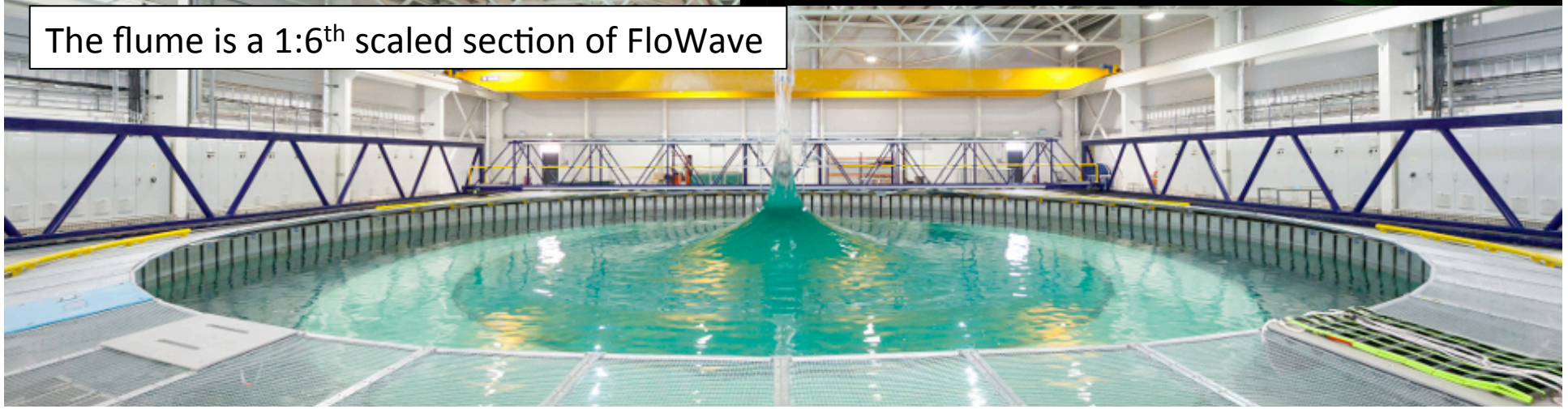
Flume 0.4x0.4 m, U=0.2 m/s
H_{wave}=0.06 m, f=1 Hz
c=0.15m, b=0.3m, α=5°

NACA 4415: CONNEX 500 3D printer
Continuous variation of different rubbers





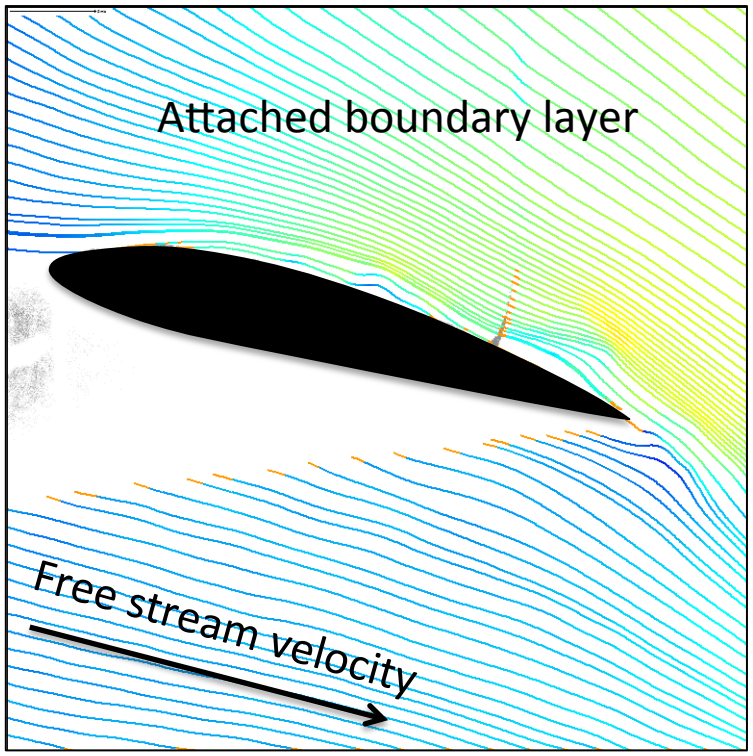
The flume is a 1:6th scaled section of FloWave



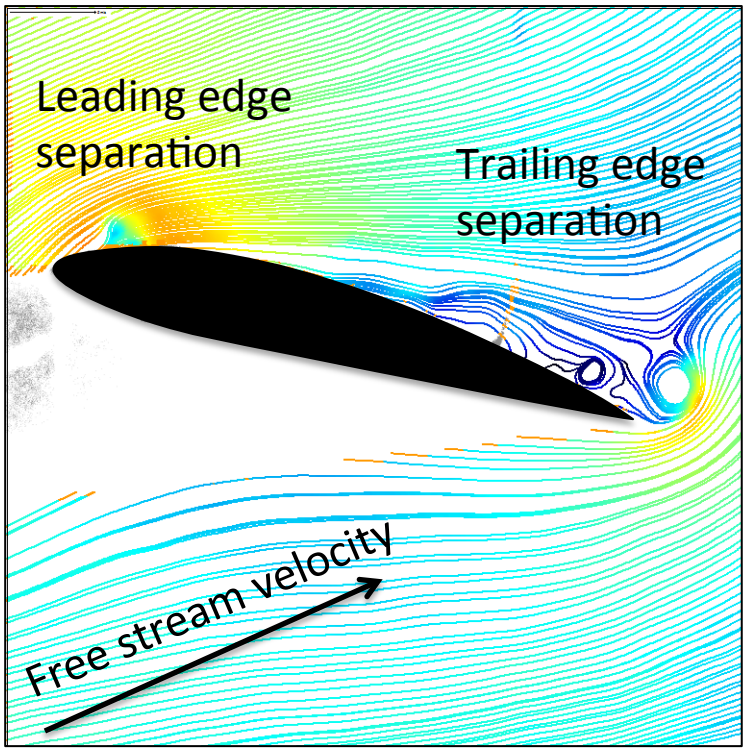
Flow measurements

Examples of PIV measurements in the UoE Hydro Lab

t_0



t_1

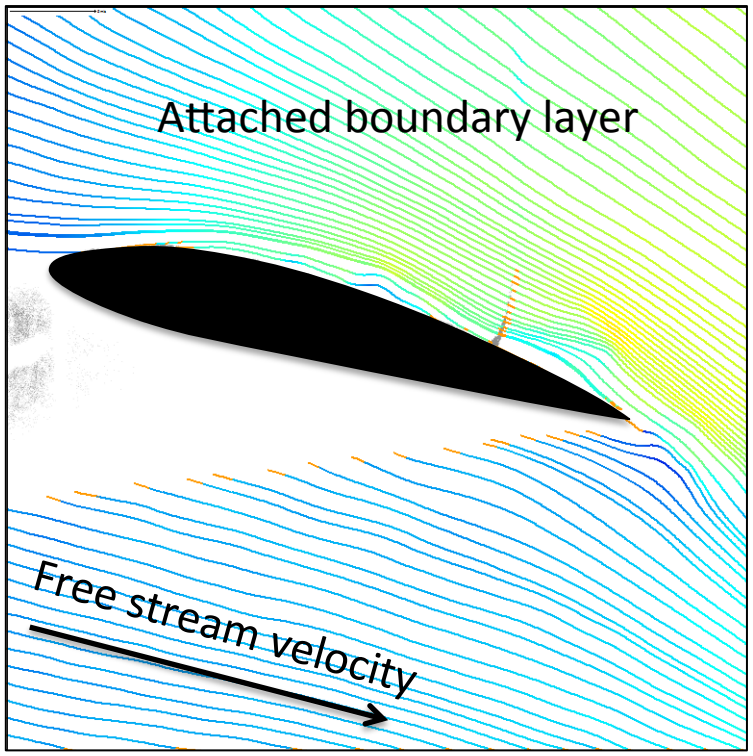


Viola et al., OTEW, 2015

Flexible trailing edge

A potential mechanism to decrease load fluctuations
is bending the trailing edge in high-α high-speed conditions

t_0



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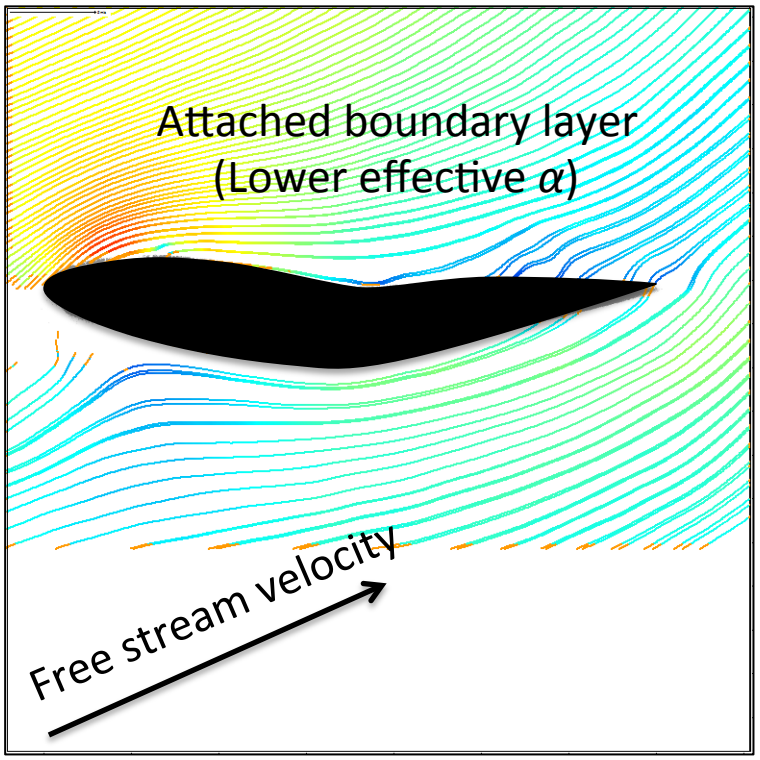
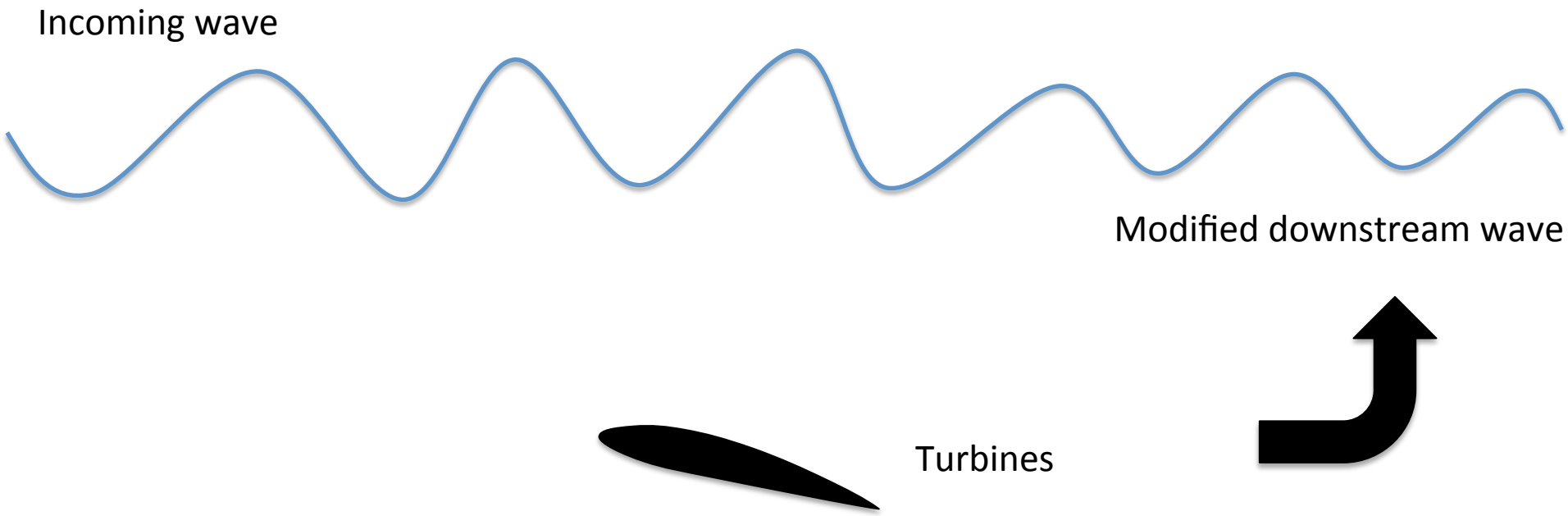


Viola et al., OTEW, 2015

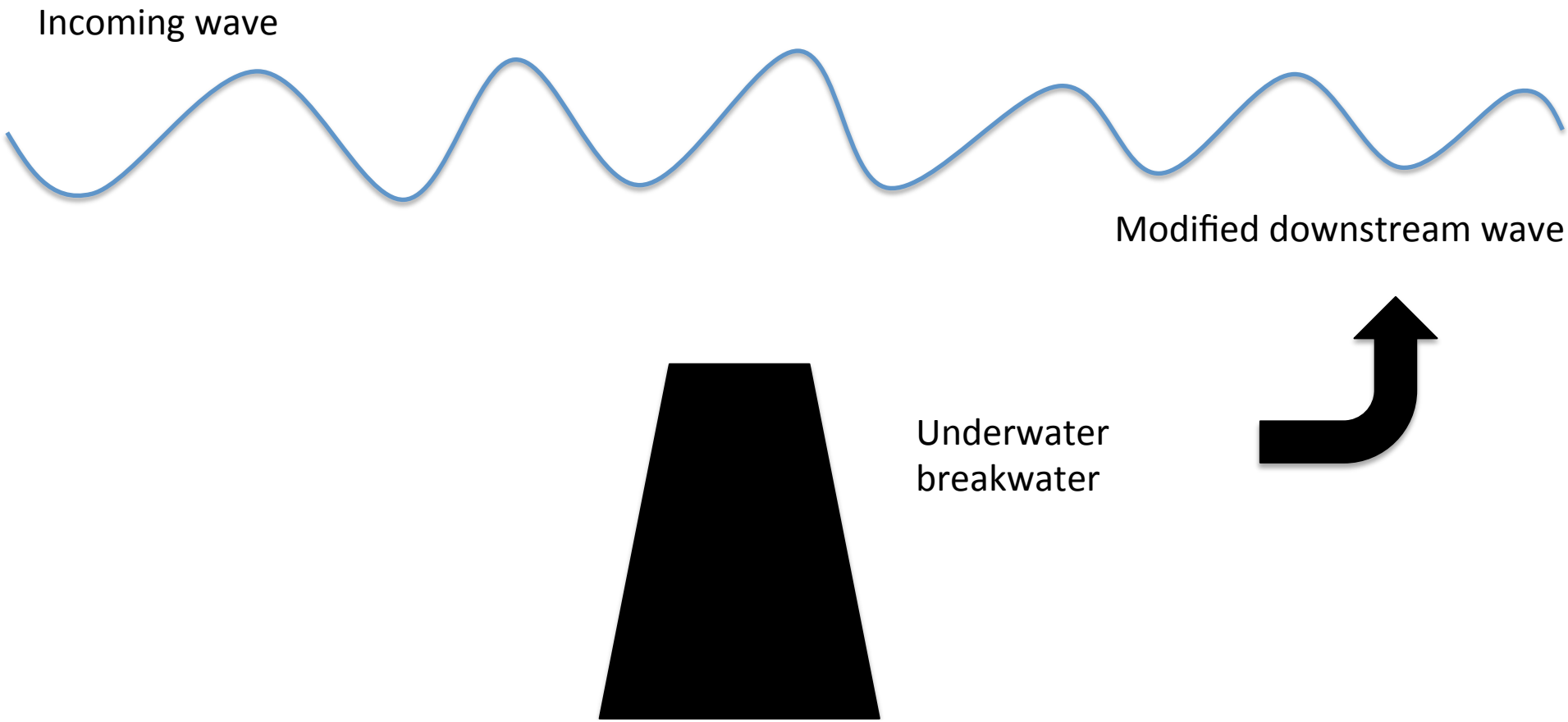
2. Effect of turbine on wave

How is the incoming wave modified by an underwater tidal turbine?



2. Effect of turbine on wave

How is the incoming wave modified by a generic underwater body such as, for instance, a breakwater?



Aim

- Massel (1983) observed that waves over a submerged body transfer energy from their fundamental mode to higher harmonics
- Grue (1992) found that more than 25% of the incoming energy flux may be transferred to shorter waves
- Rambabu & Mani (2005) showed that there is an optimum wave height over water depth ratio that leads to minimum energy transmission

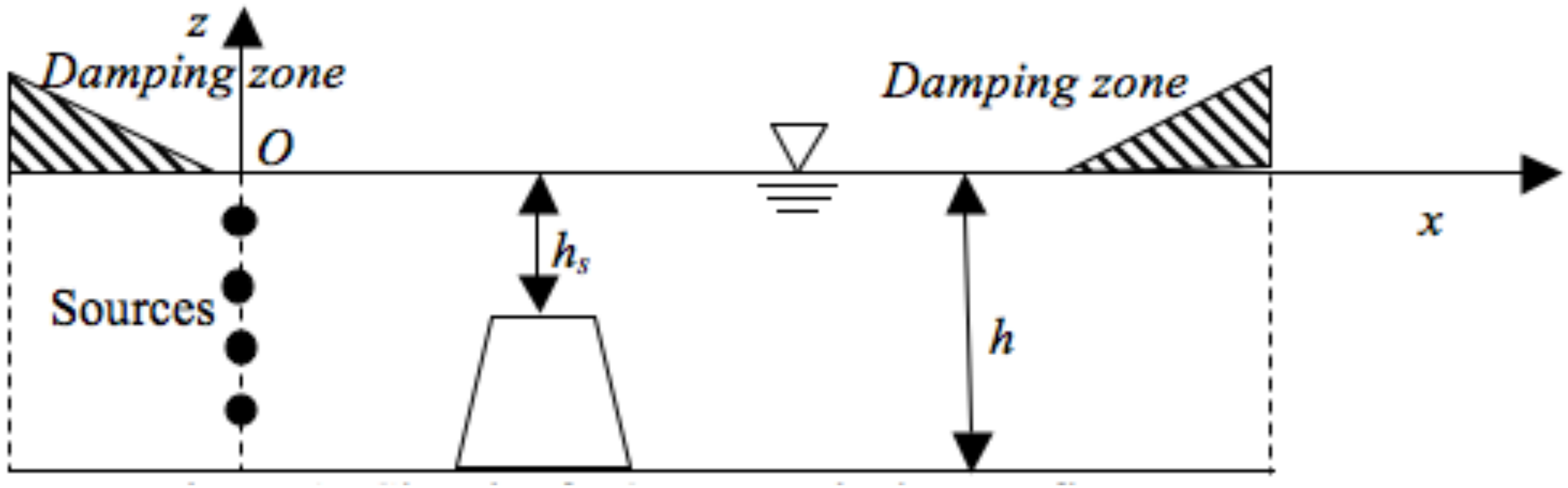
Aim

Study the influence of the submerged body size and relative position with free surface and seabed on the energy transfer from fundamental mode to the free harmonic waves

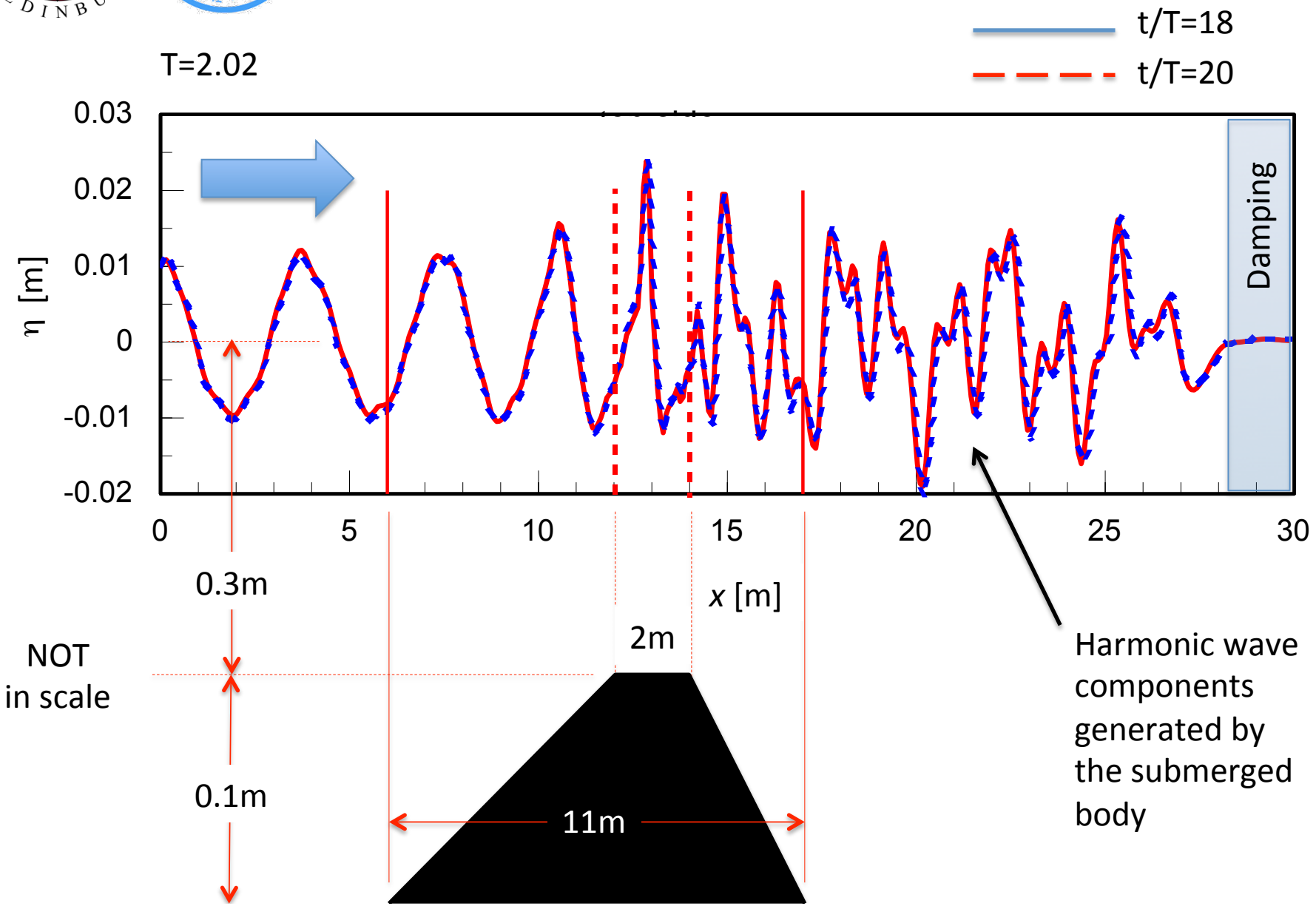
Is there a configuration that leads to a minimum or maximum transmission?

Method

- 2D Boundary element method
- Free surface is solved with a mixed Eulerian-Lagrangian scheme
- Temporal discretisation is solved with a 4th order Runga-Kutta scheme
- Free and bound harmonics are separated with a four-point method



Validation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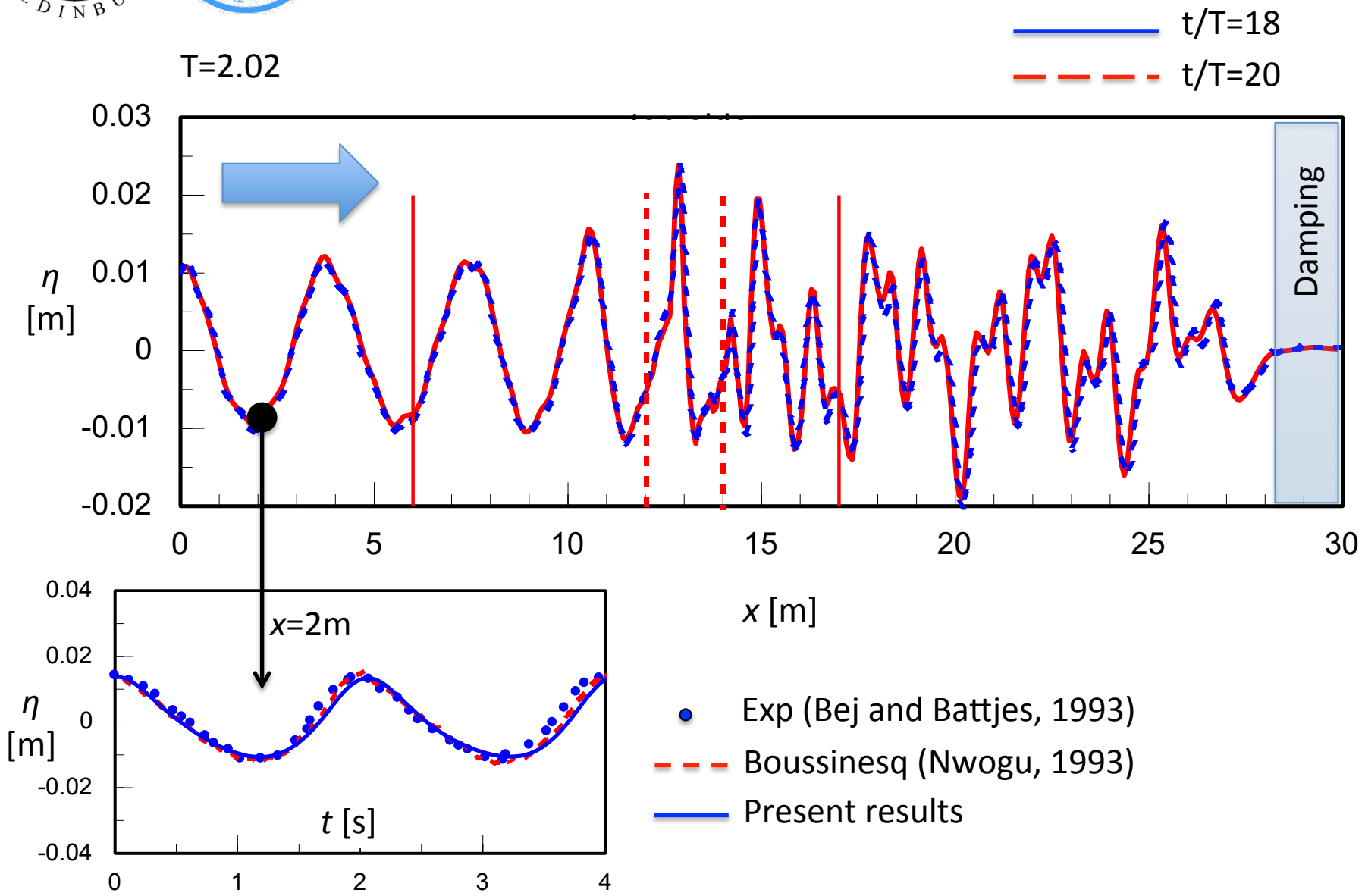
t/T=20
T=2.02
0.03
0.02
0.01
0
-0.01
-0.02
η [m]
0
5
10
15
20
25
30
x [m]
Damping
0.3m
NOT
in scale
0.1m
2m
11m
Harmonic wave components generated by the submerged body

Validation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t/T=20
T=2.02
0.03
0.02
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0
-0.01
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Damping
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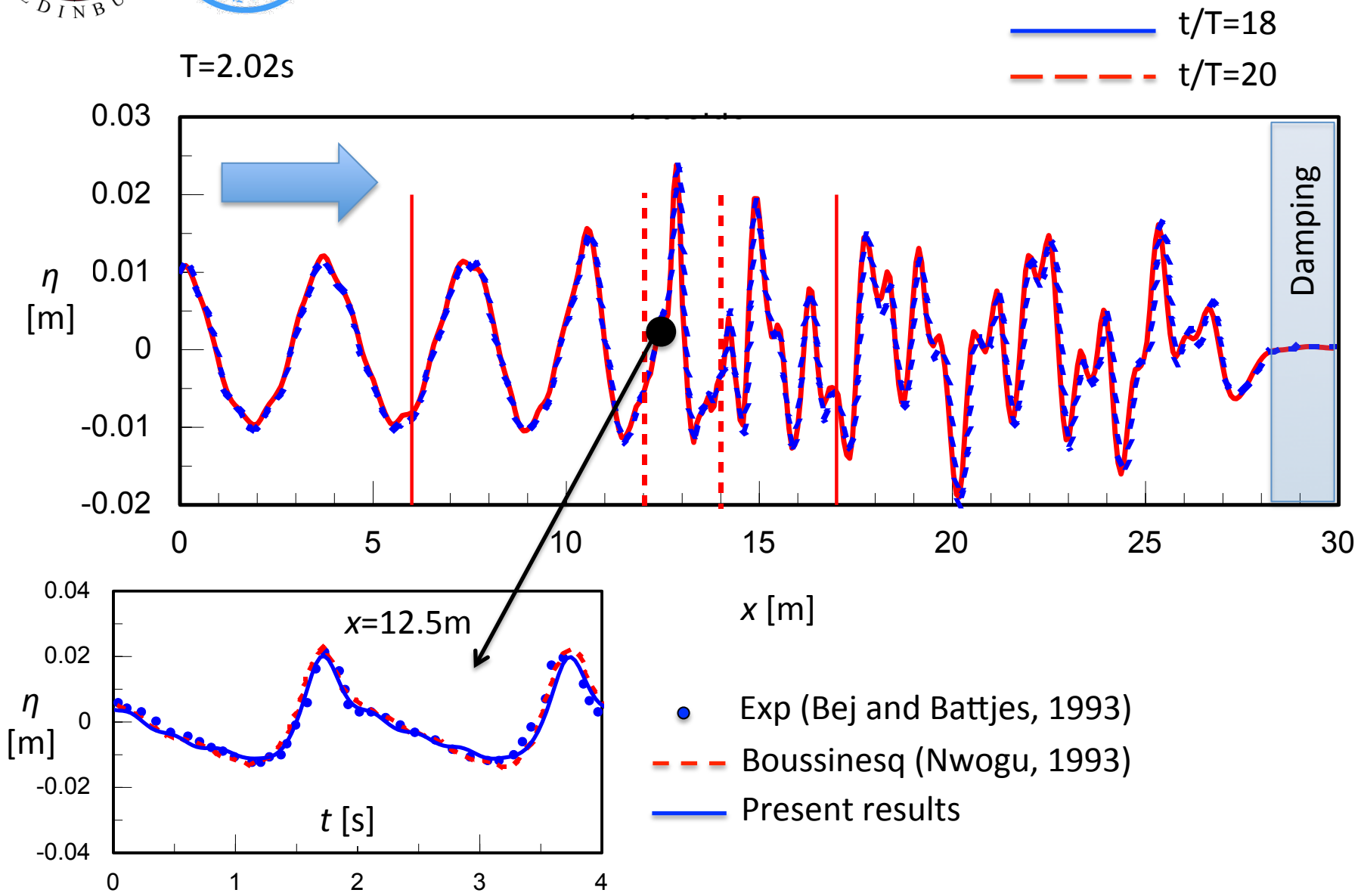
5
10
15
20
25
30
x [m]
x=2m
0.04
0.02
0
-0.02
-0.04
η
[m]
t [s]
0
1
2
3
4
Exp (Bej and Battjes, 1993)
Boussinesq (Nwogu, 1993)
Present results

Validation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t/T=20
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-0.01
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Damping
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x [m]
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-0.02
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η
[m]
x=12.5m
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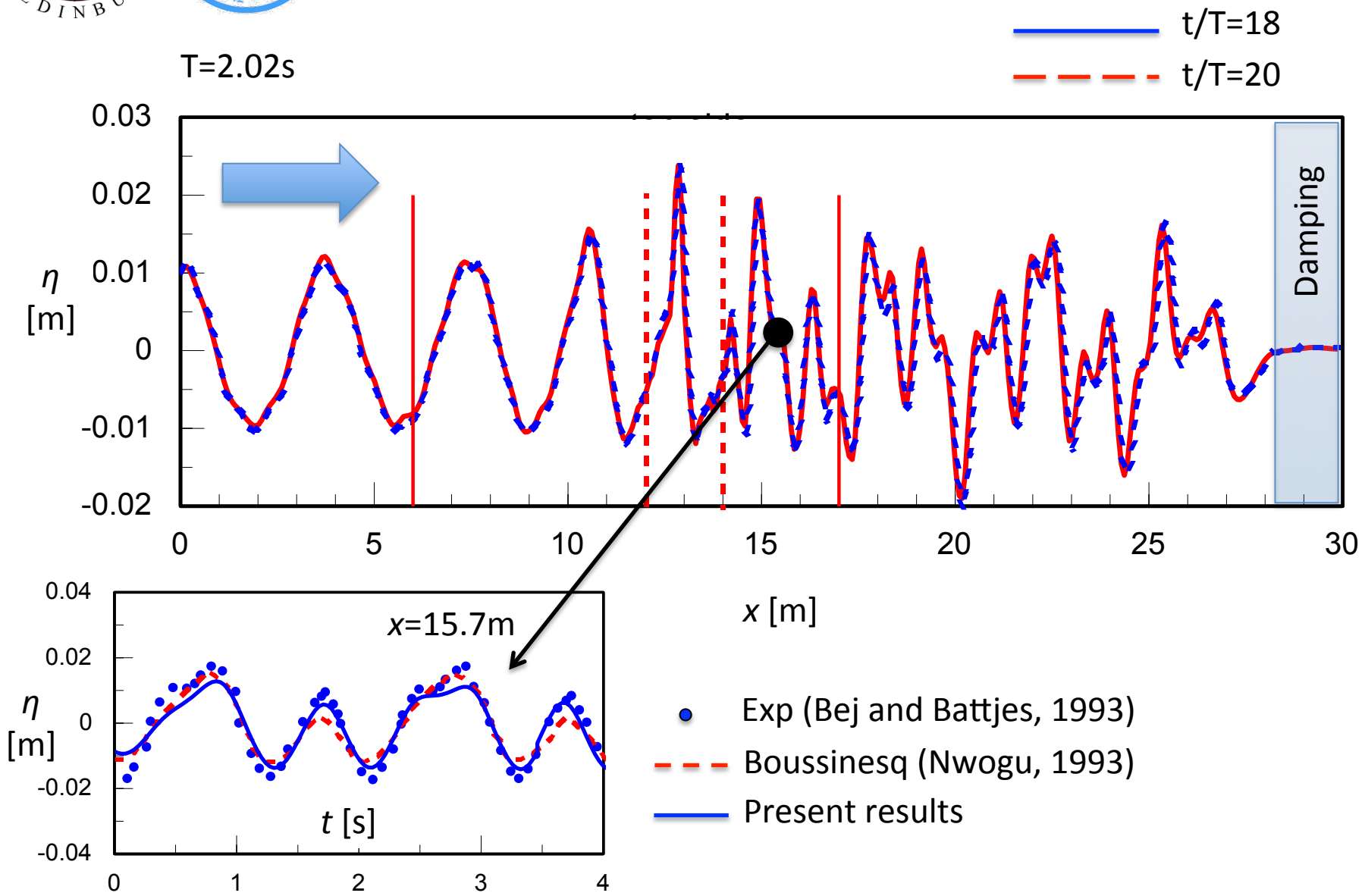
Exp (Bej and Battjes, 1993)
Boussinesq (Nwogu, 1993)
Present results

Validation


t/T=18
t/T=20
T=2.02s
0.03
0.02
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0
-0.01
-0.02
η
[m]
Damping
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5
10
15
20
25
30
x [m]
0.04
0.02
0
-0.02
-0.04
η
[m]
x=15.7m
t [s]
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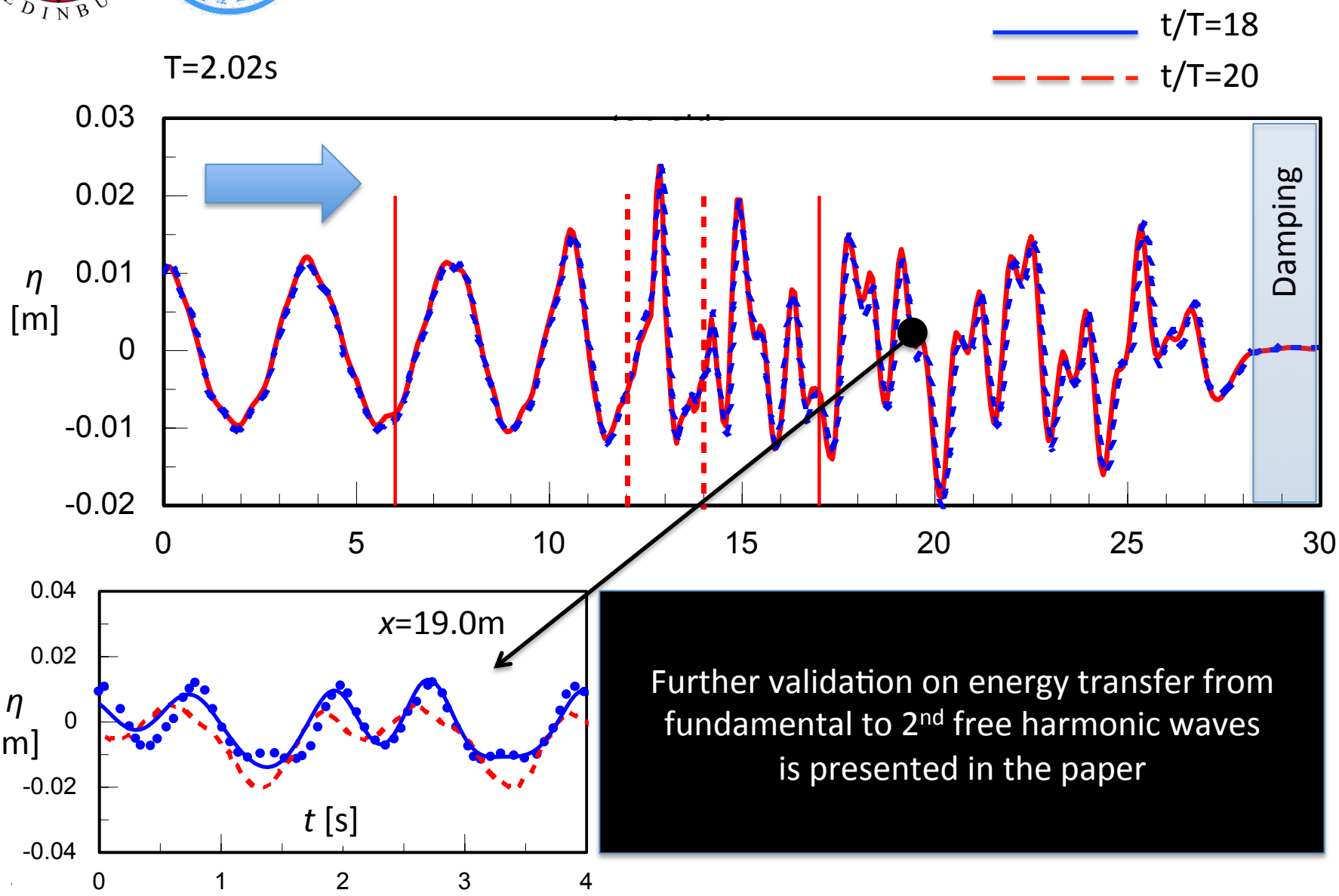
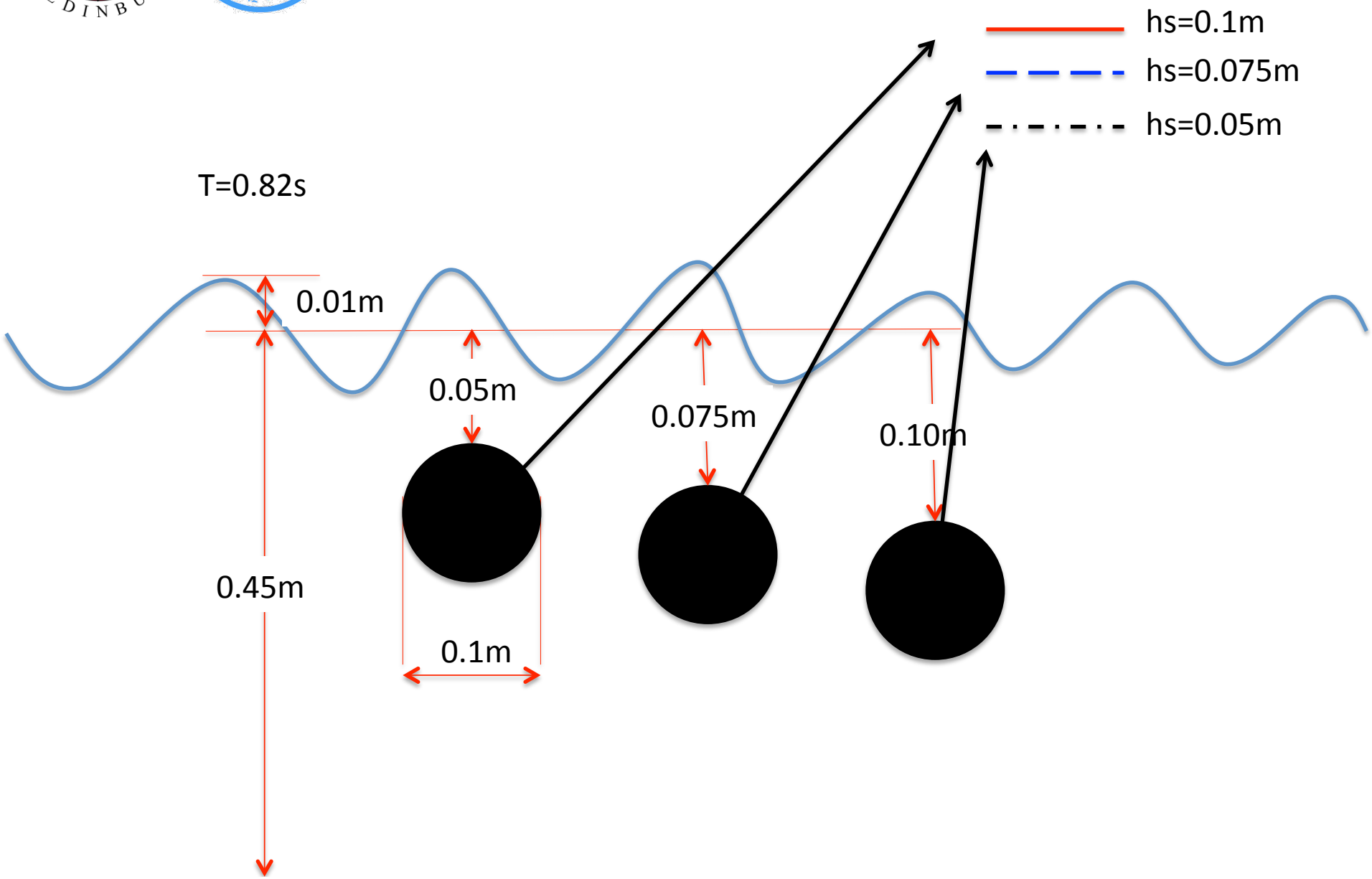
2
3
4
Exp (Bej and Battjes, 1993)
Boussinesq (Nwogu, 1993)
Present results

Validation

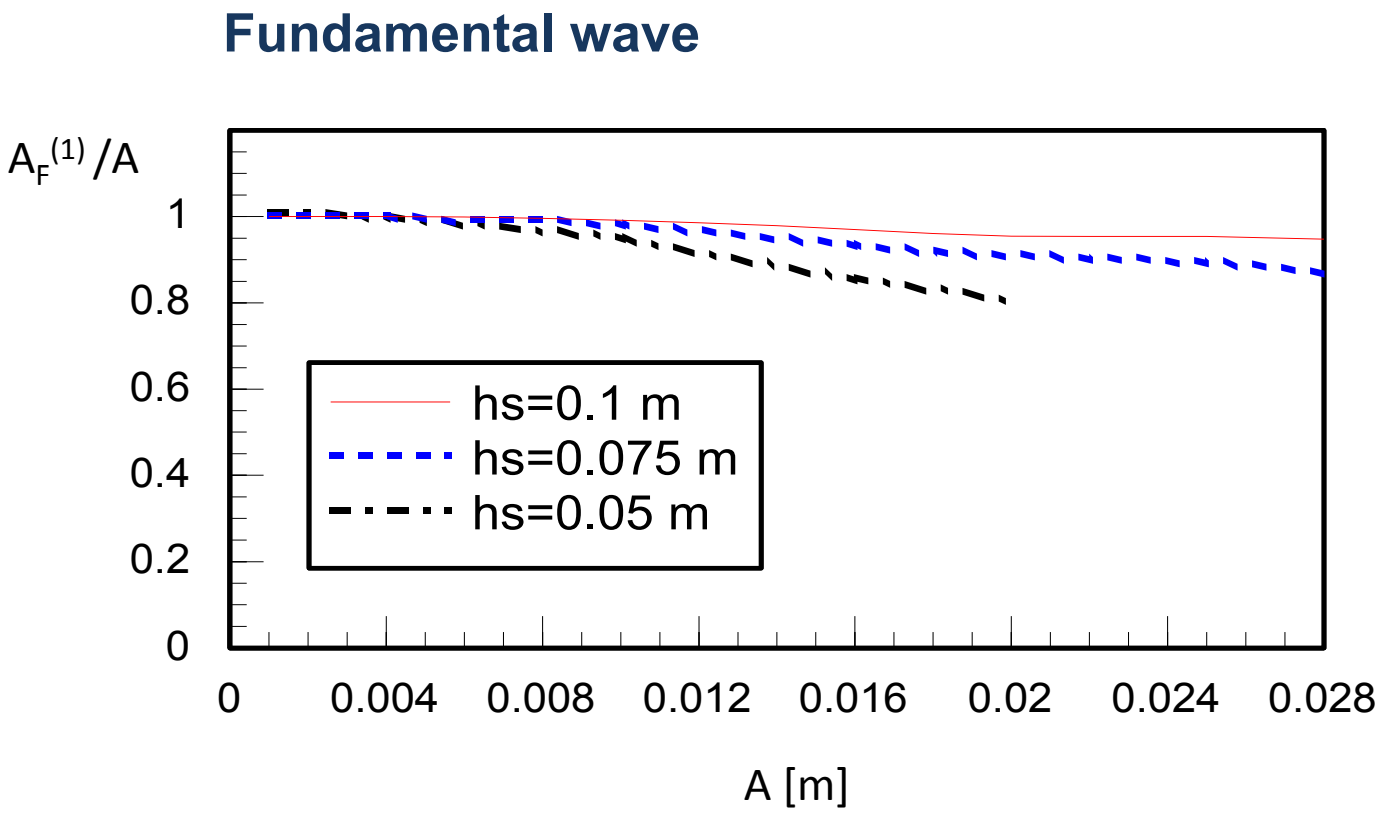


Further validation on energy transfer from fundamental to 2nd free harmonic waves is presented in the paper

Effect of submerged depth

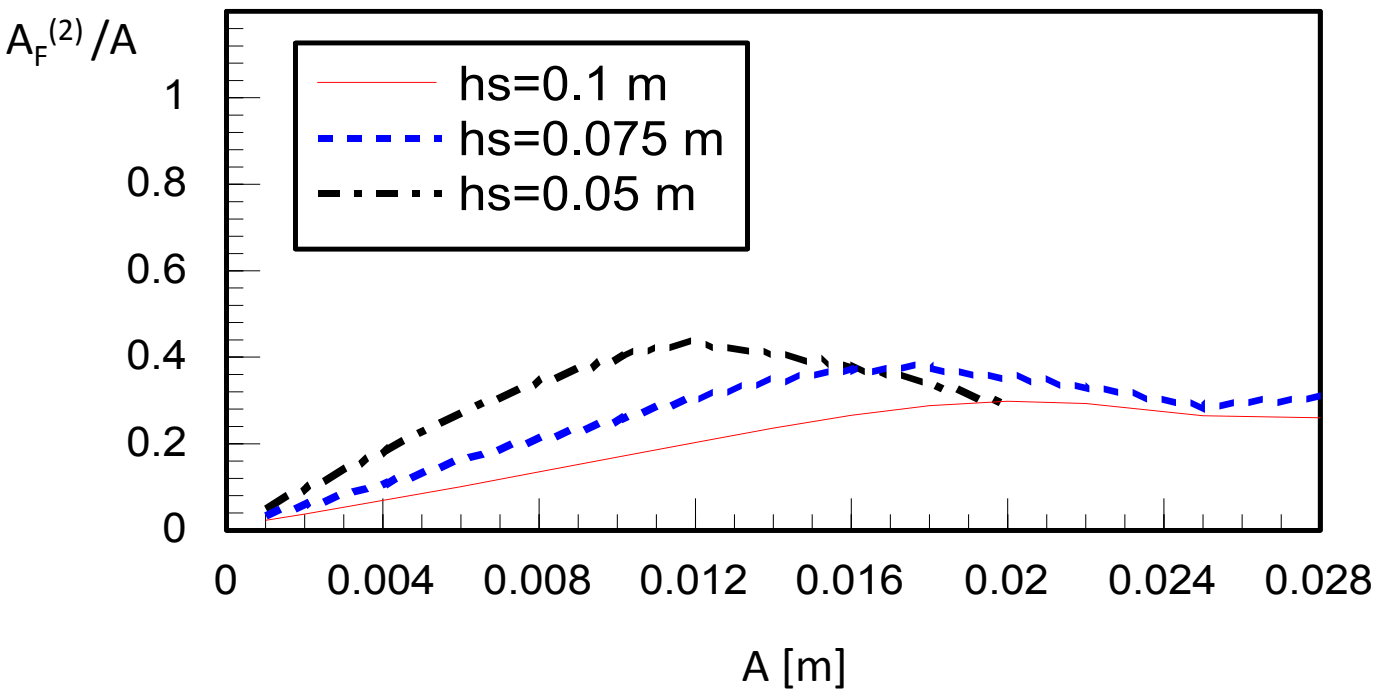


Effect of submerged depth

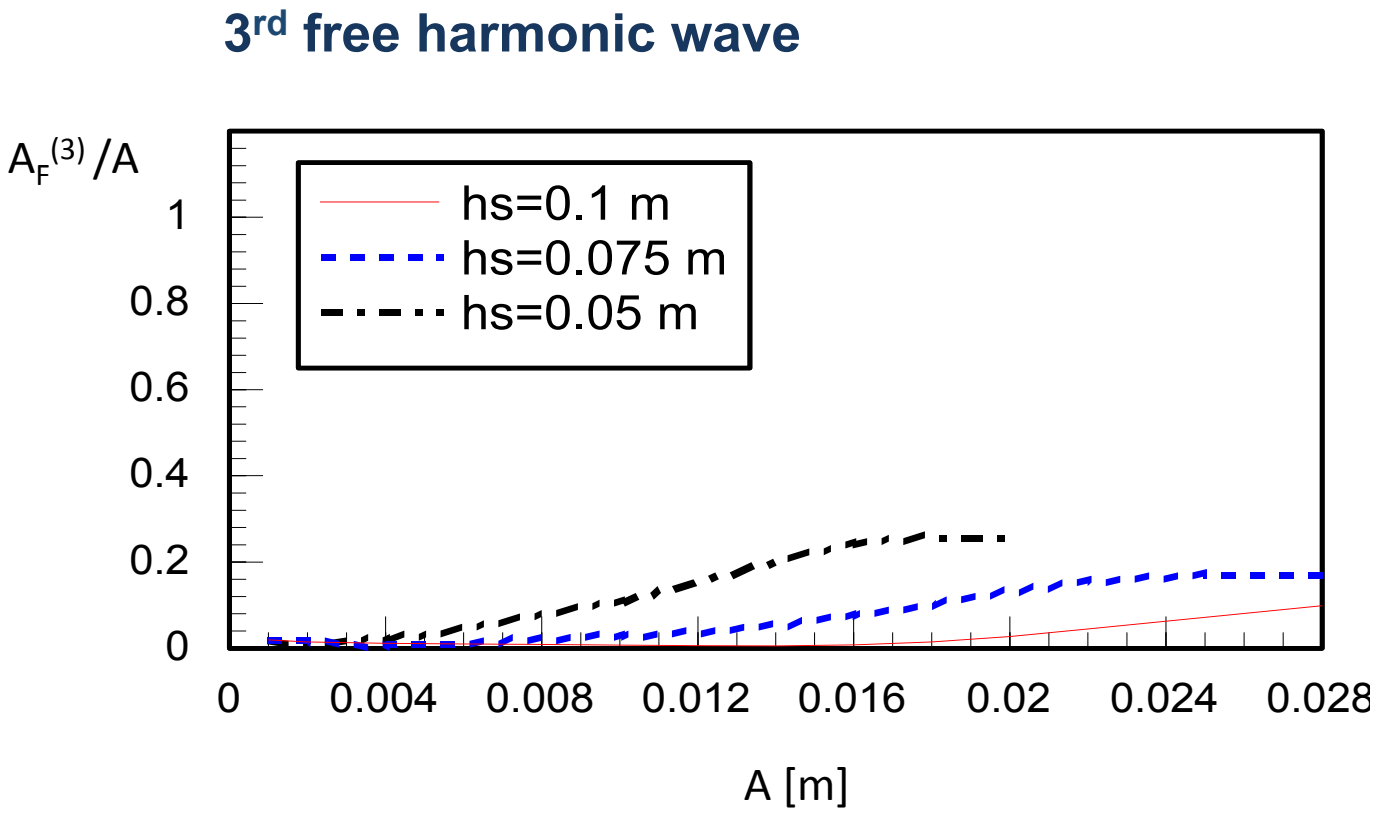


Effect of submerged depth

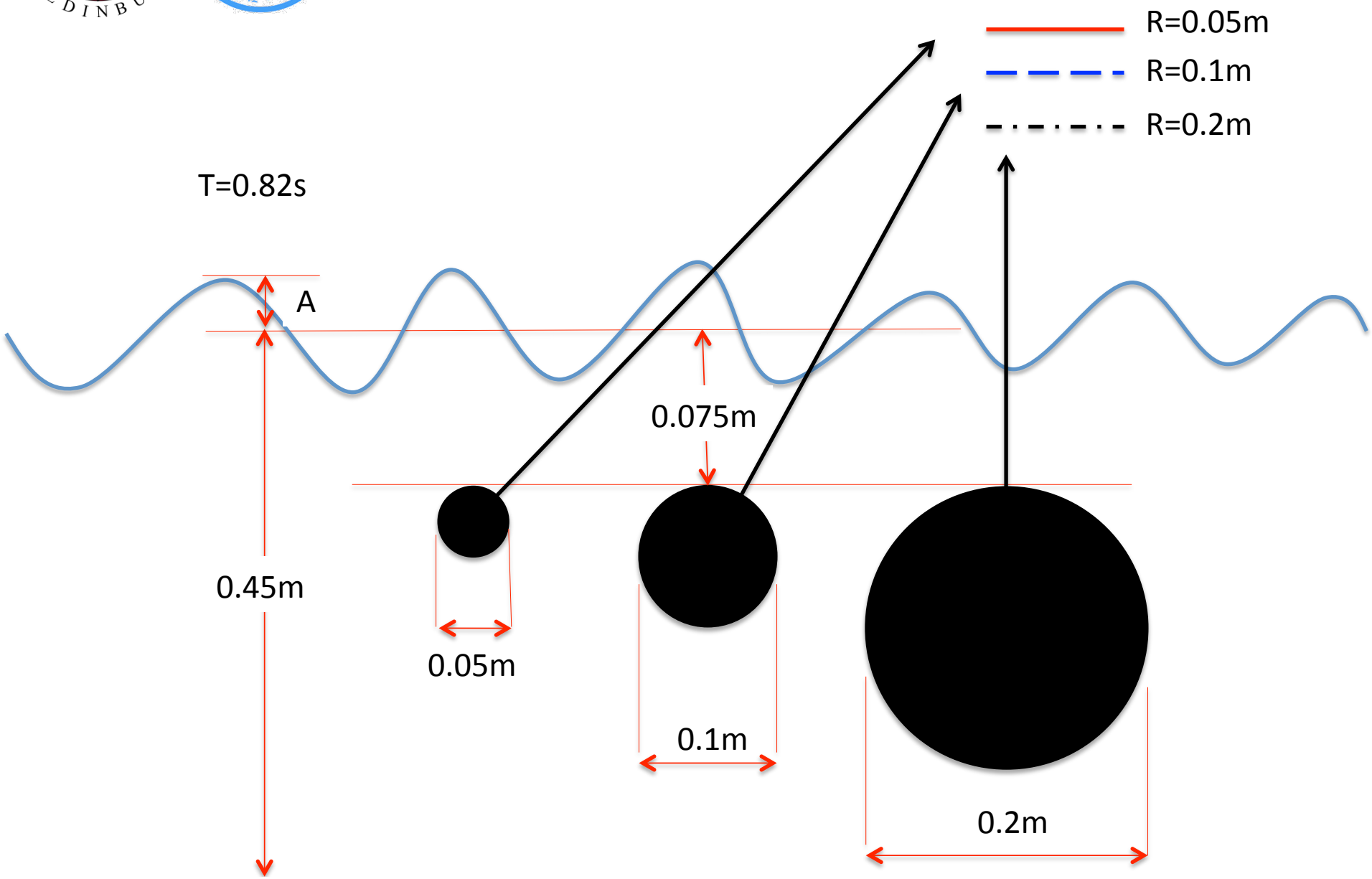
2nd free harmonic wave



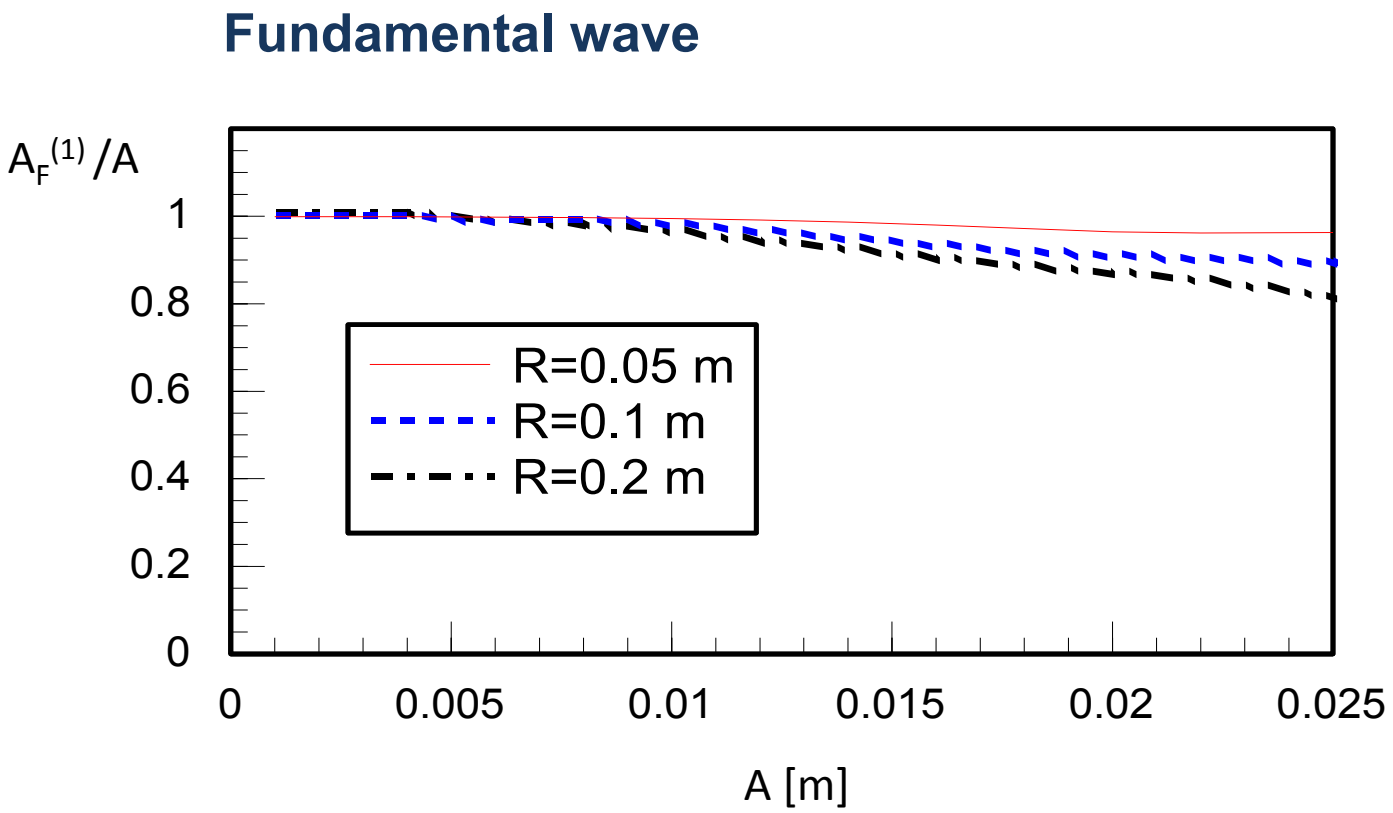
Effect of submerged depth



Effect of body size

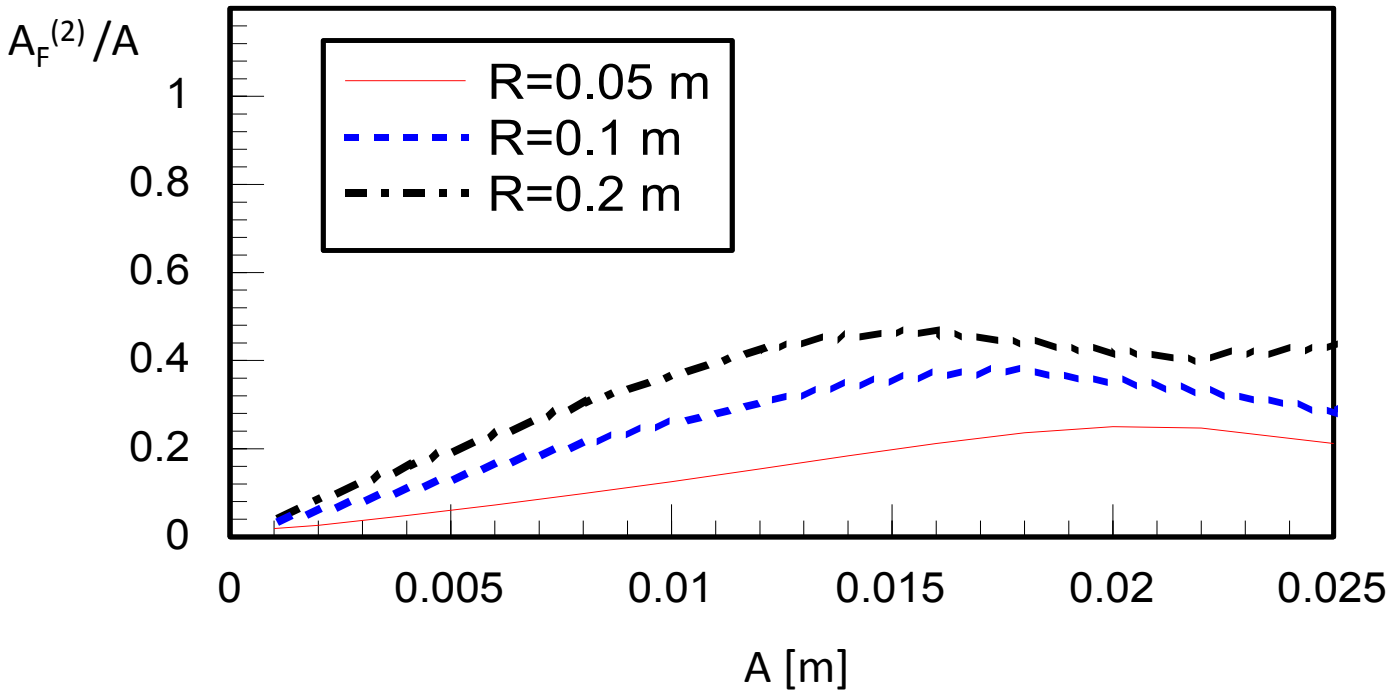


Effect of body size

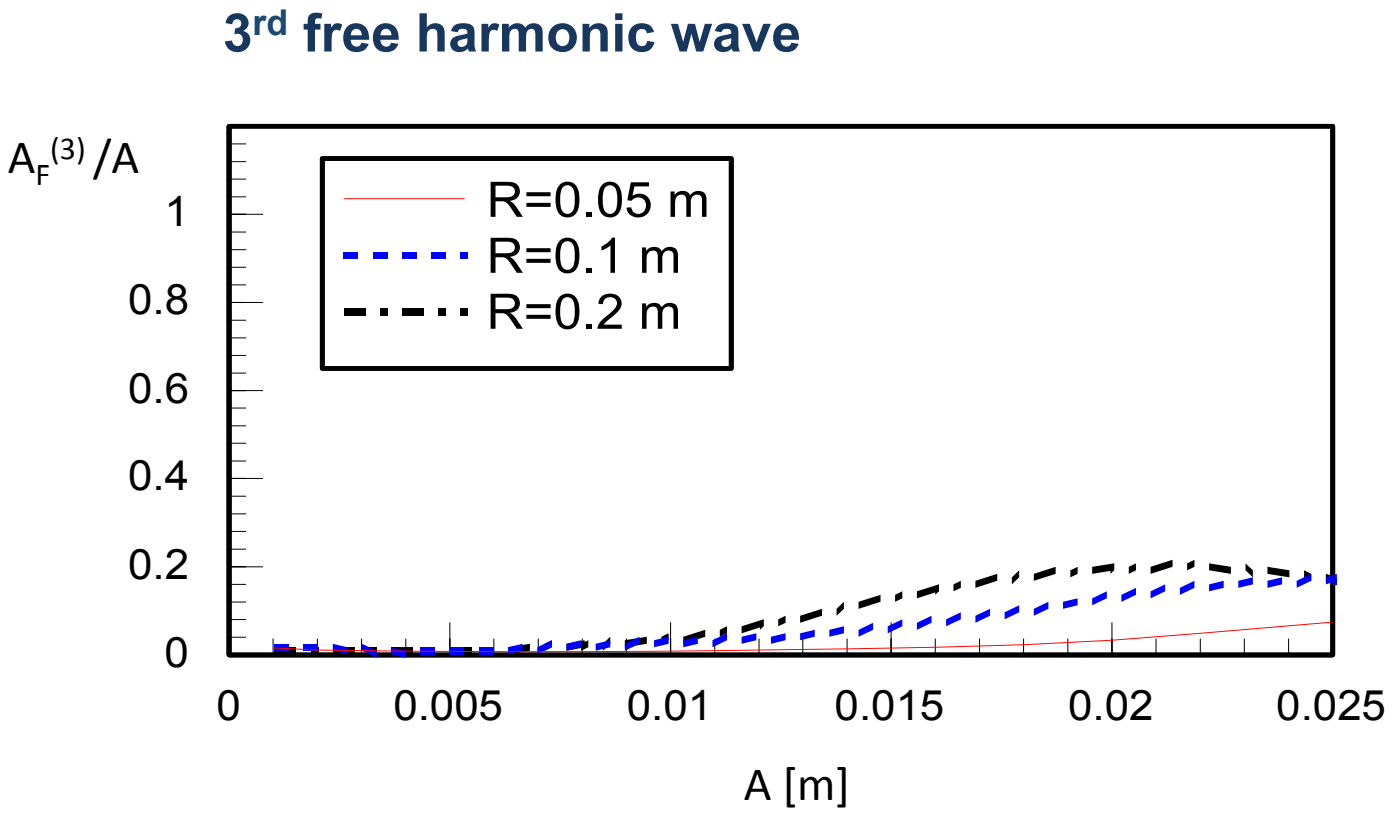


Effect of body size

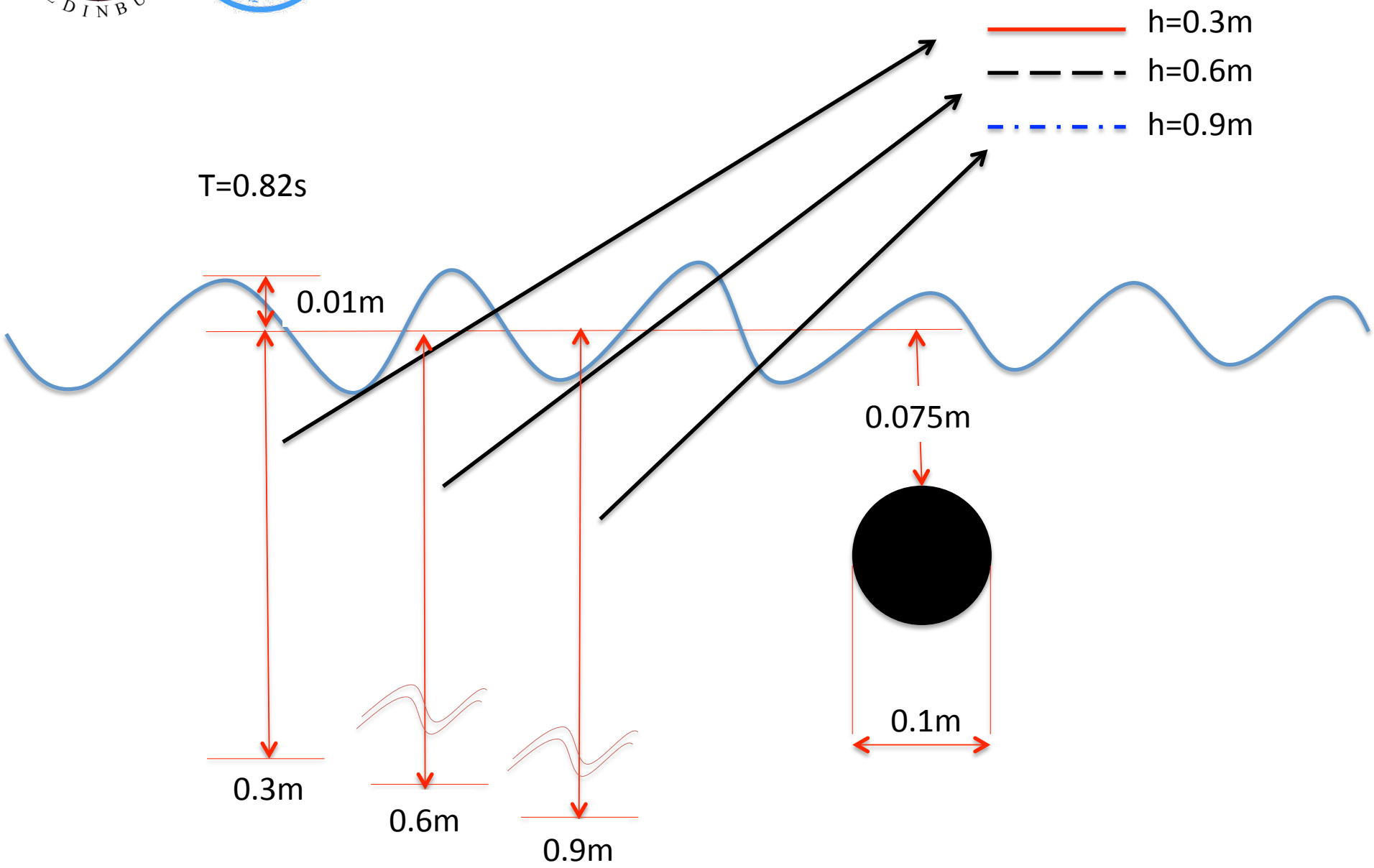
2nd free harmonic wave



Effect of body size

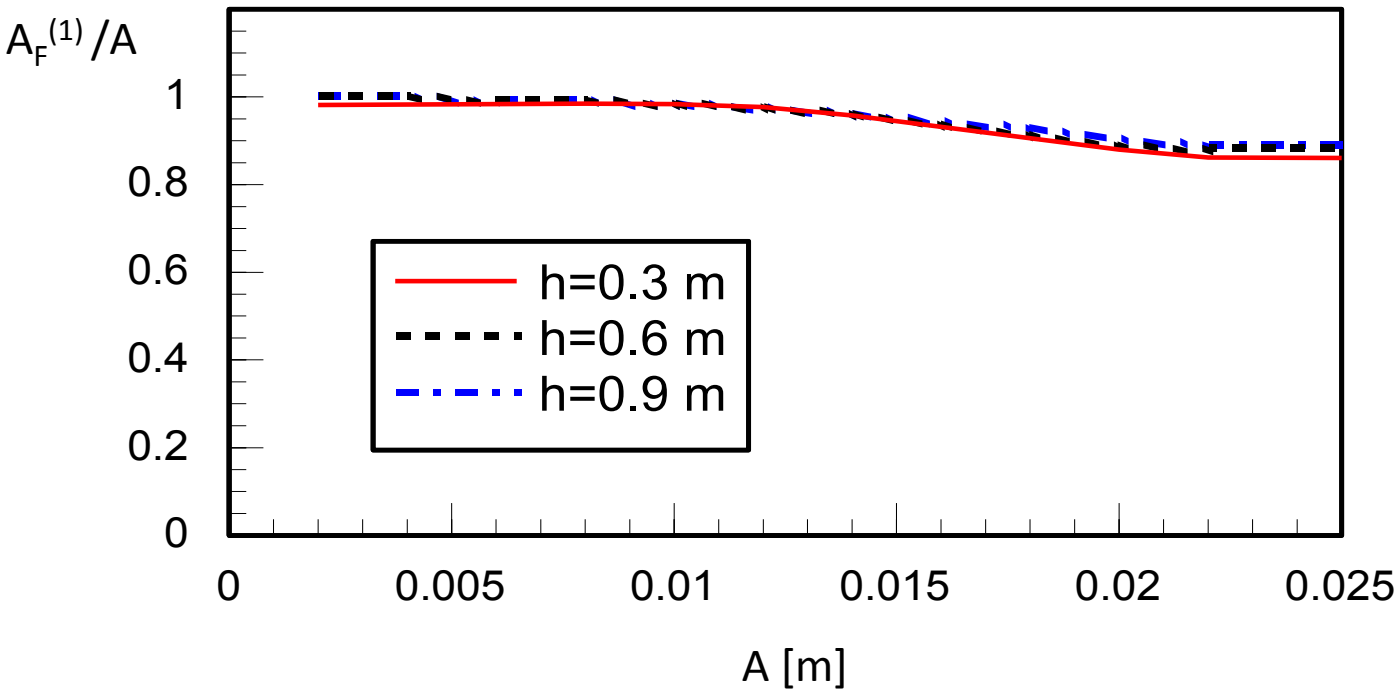


Effect of water depth



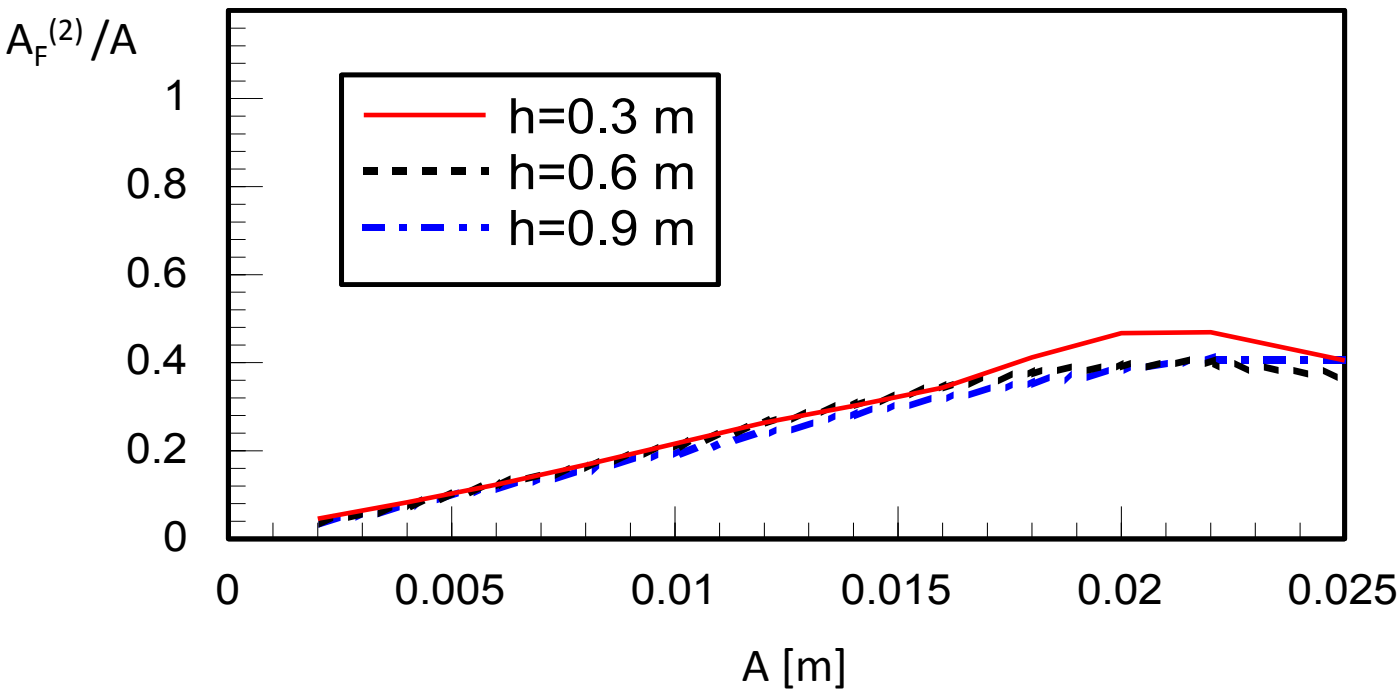
Effect of water depth

Fundamental wave

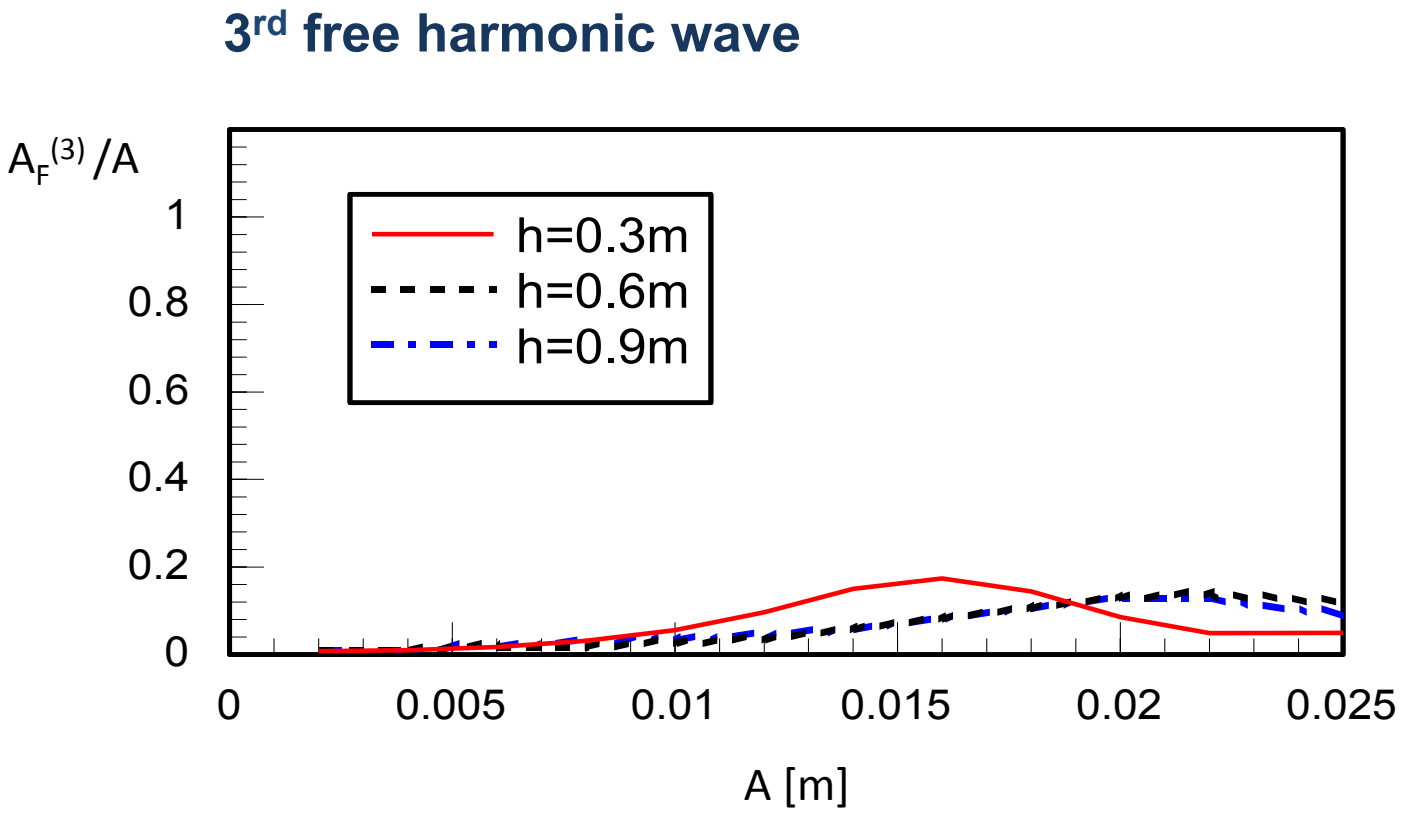


Effect of water depth

2nd free harmonic wave



Effect of water depth



Conclusions

We developed a numerical tool to study the energy transfer from the fundamental wave mode to higher free harmonic waves

1. Transfer increases with body size, nearness to the free surface and water shallowness

2. The smaller the body, the closer to the free surface and the shallower the water depth, the smaller wave amplitude where the maximum transfer (in percentage) occurs

3. The effect of water depth decreases for increasing depth and becomes negligible when higher than six body lengths

Acknowledgments

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Newton Fund